Heteroepitaxy and Selective Epitaxy for Discrete and Integrated Devices

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***Abstract*—We present first results on heteroepitaxy of InP on silicon on insulator (SOI). We also demonstrate InP nanopillar fabrication by means of selective epitaxy. Selective epitaxy is also exploited to fabricate advanced photonic integrated devices for Optical Code Division Multiplex Access (OCDMA) networking applications.**

Keywords: Heteroepitaxy; selective epitaxy; nanopillars; Hydride vapour phase epitaxy; OCDMA devices

I. Introduction

Studies on the SOI platform for the ultimate aim of integrating III-V active devices and Si photonic devices on the same Si substrate are of paramount importance [1-2]. Here we demonstrate heteroepiaxial growth of InP on SOI by ELOG (epitaxial lateral overgrowth) on which even an InGaAsP/InP MQW (multi quantum well) structure ($\lambda \sim 1.55$ μm) can be grown. We present results of cathodoluminescence (CL) and micro photoluminescence (μ-PL) studies.

As a prestudy to realize nanopillars of InP on silicon or SOI for nanodevice integration, we have studied nanopillar growth on InP by selective epitaxy. So far, GaAs, InP and InGaAs pillars have been grown mostly on (111) surfaces [3-4]. We demonstrate here that InP nanoplillars can be grown even on (001) surface.

Finally we also demonstrate that selective epitaxy of InP:Fe on InGaAsP/InP systems can be successfully used to monolithically integrate OCDMA devices for realizing optical codes to configure network access. As an example we demonstrate all-optical encoding and decoding using InGaAsP/InP OCDMA chips containing arrayed waveguide gratings and phase modulators.

II. Experiments

A. Heteroepitaxy of InP on SOI

Precoated InP by Metal-Organic Vapor Phase Epitaxy (MOVPE) on (001) SOI substrate with exact orientation was used as the seed layer to provide ELOG of InP. ELOG of InP was conducted on patterned substrate by Low-Pressure Hydride Vapor Phase Epitaxy (LP-HVPE). The ring patterns prepared by conventional methods were similar to those employed earlier for ELOG of InP on Si and subsequent growth of MQW [5]. CL measurements were carried out at ~80 K using an electron beam energy of 15 keV and a probe current ~ 2nA.

B. InP nanopillars

Openings of various sizes patterned according to a triangular lattice on (001) InP were formed by using e-beam lithography. HVPE was used to grow InP nanopillars selectively in these openings. The grown pillars were analysed by Atomic Force Microscopy (AFM).

C. OCDMA devices

LP-HVPE allows selective lateral epitaxy of InP:Fe on curved sidewall surfaces of dry etched waveguides. This capability is extremely useful in many integrated photonic device applications. A spectral-phase-encoded time-spreading (SPECTS) O-CDMA system uses an arrayed waveguide grating (AWG) for spectral demultiplexing, an array of phase modulators for spectral phase encoding, and another AWG for spectral multiplexing so that input ultra-short optical pulses will be spectrally phase encoded for data transmission [7].

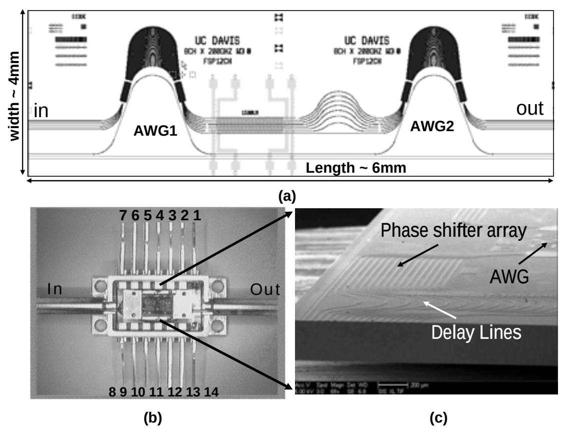

Figure 1. (a) O-CDMA encoder chip layout, (b) packaged O-CDMA encoder chip and (c) SEM picture of the device.

Figure 1(a) shows the O-CDMA encoder mask layout. The AWG pair achieves spectral de-multiplexing and multiplexing, and the phase modulators between the AWGs apply a phase value corresponding to the O-CDMA code to each de-multiplexed spectral channel. The combination of input and output waveguides are chosen for an optimal wavelength match of the two AWG responses. The delay lines equalize the optical path lengths of the spectral channels. A CH_4-H_2 RIE etch defined ridge waveguides by etching through the waveguiding core layer. Subsequently, a LP-HVPE growth buried the ridge waveguides by laterally depositing a semi-insulating Fe-doped InP layer, forming a buried heterostructure. The HVPE regrowth process has a highly enhanced growth rate in the lateral direction so that a single regrowth step results in a planarized BH waveguide with sidewall passivation, electrical isolation, and surface planarization. The fabricated encoder chip was wire-bonded and packaged in a butterfly package for programmable electrical access to the phase shifter arrays. Figures 1 (b) and (c) show the packaged chip and a scanning electron micrograph (SEM) picture of the chip, respectively.

III. Results and Discussions

A. *Heteroepitaxy of InP on SOI*

CL on InP/SOI (not shown here) exibits a peak at 876 nm, attributed to band-band transition of InP and a second peak, near 899 nm, to the transition between the conduction band and an acceptor level related to carbon. In certain regions, a granular structure is observed which yield additional spectral features at lower energies. These peaks are mostly related to Si and O impurities. Moreover, a shoulder near the main peak is the signature of the presence of strain in this region. Room temperature µ-PL investigation on MQW grown on InP/SOI shows a peak at 1520 nm. Although the signal is weak, the FWHMs for InP and MQW on SOI are comparable (~ 95 nm).

B. *InP nanopillars*

Figure 2 shows the AFM image of the nanopillars grown on openings of different sizes patterned according to a triangular lattice.

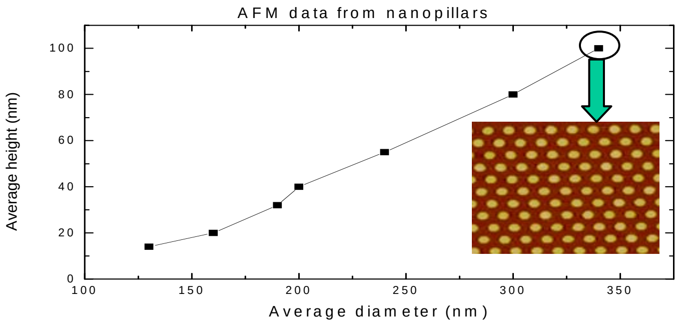

Figure 2. Height vs. diameter of the InP pillars. Insert is an array of 350 nm diameter and 100 µm tall InP pillars.

The growth rate is exceptionally low and hence the pillar height is not more than 100 nm in this study. Pillars grown on larger diameters were hexagonal in shape, although these were grown on (001) surfaces. This is particularly interesting since such a faceting can be used to sensitize the surfaces with certain molecules. This facility leads to applications in biosensing and bio-analysis [6]. Thus further extension of these studies would pave the way for optoelectronic integration for bio-applications.

C. *OCDMA devices*

Two packaged OCDMA micro chips of Figure 1 (b) were used to encode and decode the optical pulses by applying voltages on the phase modulator arrays corresponding to desired optical codes. Figure 3 shows cross correlation traces of the encoder output (a) for incorrectly decoded signal (W5 encoding and W6* decoding), and (b) for correctly decoded signal. (W5 encoding and W5* decoding). Clear contrast at *t*=0 allowed successful O-CDMA networking applications.

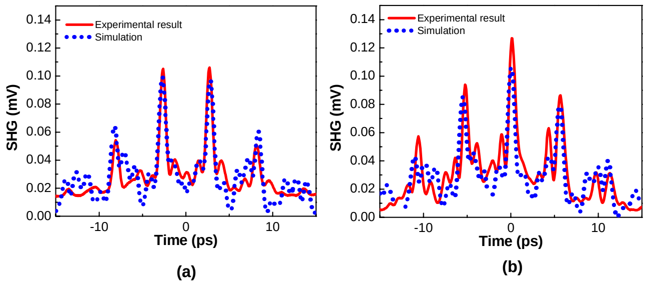

Figure 3. Cross-correlation traces of the encoder-decoder output (a) for incorrectly decoded signal (W5 encoding and W6* decoding), and (b) for correctly decoded signal (W5 encoding and W5* decoding).

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